

## CLAIMS

What is claimed is:

- 1     1.     An apparatus comprising:  
2           a wavelength division multiplexing optical network including optical network  
3           devices, interconnected by links, that propagate along said links  
4           connectivity request messages, initiated at each of said optical network  
5           devices acting as an access node, to discover possible end to end paths  
6           that meet a set of zero or more connectivity constraints, wherein an end  
7           to end path is a series of two or more of said optical network devices  
8           connected by links on which a set of wavelengths is available for  
9           establishing a lightpath; and  
10          said optical network devices acting as access nodes each including a database  
11          representing available paths with costs from that access node to  
12          reachable destination nodes, each of said paths having associated with it  
13          in said database the wavelengths available on that path.
- 1     2.     The apparatus of claim 1, wherein each of said databases stores said available  
2     paths grouped by common destination nodes and sorted in each group at least in part by  
3     the cost.
- 1     3.     The apparatus of claim 1, wherein said available paths include lightpaths.
- 1     4.     The apparatus of claim 1, wherein said available paths include one or more of  
2     optical circuits, lightpaths, and end-to-end unidirectional paths.
- 1     5.     The apparatus of claim 1, wherein each of said available paths in each of said  
2     databases is a sequence of optical network devices and interconnecting links.
- 1     6.     The apparatus of claim 5, wherein the wavelengths available on each of said  
2     available paths are those wavelengths common to all of the interconnecting links of that  
3     path.

1 7. The apparatus of claim 1, wherein said optical network devices acting as access  
2 nodes each also includes:

3 a regular path module to select from said available paths a path and an  
4 unallocated wavelength thereon.

1 8. The apparatus so claim 1, wherein said optical network devices acting access  
2 nodes each also includes:

3 a disjoint path module to, based on an input path and said database, select from  
4 ones of said available paths a disjoint path and an unallocated  
5 wavelength thereon.

1 9. The apparatus of claim 8, wherein each of said disjoint path modules is at least  
2 to determine at least one of fully node disjoint type paths and maximally node disjoint  
3 type paths.

1 10. The apparatus of claim 8, said each of disjoint path modules is at least to  
2 determine at least one of fully link disjoint type paths and maximally link disjoint type  
3 paths.

1 11. The apparatus of claim 1, wherein said optical network devices acting as access  
2 nodes each also includes:

3 a demand module to respond to requests for paths received by said access node;  
4 a path selection module to, based at least in part on input destination nodes,  
5 select from the available paths in said database associated with the input  
6 destination nodes and select unallocated wavelengths thereon; and  
7 an allocate module to cause allocation said selected paths and wavelengths in  
8 real time.

1 12. The apparatus of claim 1, wherein each of said optical network devices acting as  
2 an access node builds and maintains said database.

1 13. The apparatus of claim 1, wherein each of said optical network devices,  
2 responsive to each received connectivity request message, to determine any adjacent  
3 optical network devices to which the possible end to end path that the connectivity  
4 request message has already collected can be extended to form additional possible end

5 to end paths having the originating access node as the source node and meeting the set  
6 of connectivity constraints, to transmit a message carrying that determination back to  
7 the originating access node of the connectivity request message responsive to which  
8 that message was generated for storage in the database of that node, and to propagate  
9 said connectivity request message to any adjacent optical network devices that may be  
10 able to determine additional possible end to end paths having the originating access  
11 node as the source node and meeting the set of connectivity constraints.

1 14. An apparatus comprising:  
2 an access node, to be coupled in a wavelength division multiplexing optical  
3 network, including,  
4 a database to store a representation of available paths with costs from the  
5 access node to reachable destinations organized by said  
6 reachable destinations; and  
7 a path selection module to select from said database ones of said  
8 available paths and unallocated wavelengths thereon.

1 15. The apparatus of claim 14, wherein said database includes a destinations  
2 structure to store each of said destinations in a single entry, each of said entries being  
3 associated with the sequence of nodes and links of those of the available paths that  
4 reach that entries destination, each of said series having associated with it the set of  
5 wavelengths available on the one of the available paths represented by that series.

1 16. The apparatus of claim 14, wherein said available paths include lightpaths.

1 17. The apparatus of claim 14, wherein said available paths include one or more of  
2 optical circuits, lightpaths, and end-to-end unidirectional paths.

1 18. The apparatus of claim 14, wherein each of said available paths is represented in  
2 said database by the series of two or more nodes and the interconnecting links over  
3 which that path travels.

1 19. The apparatus of claim 18, wherein each of said available paths is also  
2 represented in said database by a path channel set that includes one or more  
3 wavelengths common to all of the interconnecting links of that communication path.

- 1 20. The apparatus of claim 14, wherein said path selection module comprises:  
2 a regular path module to select from said available paths a selected path and an  
3 unallocated wavelength thereon.
- 1 21. The apparatus of claim 14, wherein said path selection module comprises:  
2 a disjoint path module to, based on an input path having a given one of said  
3 destinations, select from ones of said available paths a disjoint path and  
4 unallocated wavelength thereon.
- 1 22. The apparatus of claim 21, wherein said disjoint path module is at least to  
2 determine the intersection of the intermediate nodes of said input path and the  
3 intermediate nodes of a candidate path in said database that has the same source and  
4 destination nodes as said input path.
- 1 23. The apparatus of claim 21, said disjoint path module is at least to determine the  
2 intersection of the interconnecting links of said input path and the interconnecting links  
3 of a candidate path in said database that has the same source and destination nodes as  
4 said input path.
- 1 24. The apparatus of claim 14, wherein said access node further comprises:  
2 an allocate module, coupled to said path selection module, to cause allocation of  
3 paths and wavelengths thereon in real time.
- 1 25. The apparatus of claim 24, wherein said access node further comprises:  
2 a demand module, coupled to said path selection module and said allocate  
3 module, to respond to requests for paths received by said access node.
- 1 26. The apparatus of claim 14, wherein said access node includes additional  
2 modules to build and maintain said database in said access node.
- 1 27. The apparatus of claim 26, wherein said access node employs a distributed  
2 search based scheme to build and maintain said database.
- 1 28. The apparatus of claim 14, wherein said access node further comprises:  
2 a start up module to generate and transmit to adjacent nodes connectivity  
3 request messages to determine possible paths having said access node as

4 a source node and meeting a set of zero or more connectivity constraints;  
5 and  
6 a connectivity request module, responsive to each received connectivity request  
7 messages, to determine any adjacent nodes to which the possible path  
8 that the connectivity request message has already collected can be  
9 extended to form additional possible paths having the originating access  
10 node as the source node and meeting the set of connectivity constraints,  
11 to transmit a message carrying that determination, and to propagate said  
12 connectivity request message to any adjacent nodes that may be able to  
13 determine additional possible paths having the originating access node  
14 as the source node and meeting the set of connectivity constraints.

1 29. The apparatus of claim 28, wherein each of the messages carrying a  
2 determination is transmitted back to the originating access node of the connectivity  
3 request message responsive to which that message was generated, and wherein said  
4 start up module is also to build said database responsive to receiving the messages  
5 carrying determinations of additional possible paths having the access node as the  
6 source node and meeting the set of connectivity constraints

1 30. The apparatus of claim 14, wherein said access node further comprises:  
2 a module to build said database based upon data collected by OSPF.

1 31. The apparatus of claim 14, further comprising:  
2 a centralized network management server communicatively coupled to said  
3 access node to build and maintain the database.

1 32. The apparatus of claim 14, wherein said access node further comprises:  
2 a link state database to store, for each link connected to said access node, a link  
3 state structure to store a port of the access node to which that link is  
4 connected and available wavelengths on that link; and  
5 a link protocol module to populate said link state database.

1 33. An apparatus comprising:  
2 an access node, to be coupled in a wavelength division multiplexing optical  
3 network, including,

4 a set of modules to propagate through said optical network connectivity  
5 request messages, initiated at each of the access nodes in said  
6 optical network, to discover possible end to end paths that meet a  
7 set of zero or more connectivity constraints, wherein an end to  
8 end path is a series of two or more nodes connected by links on  
9 which a set of wavelengths is available for establishing a  
10 lightpath; and  
11 a database, to be built responsive to receiving response messages  
12 carrying determinations of possible paths having the access node  
13 as the source node and meeting the set of connectivity  
14 constraints, to store available end to end paths with costs from  
15 the access node to reachable destination nodes organized by said  
16 reachable destination nodes.

1 34. The apparatus of claim 33, wherein said database includes a destinations  
2 structure to store each of said destinations in a single entry, each of said entries being  
3 associated with the sequence of nodes and links of those of the available paths that  
4 reach that entries destination, each of said series having associated with it the set of  
5 wavelengths available on the one of the available paths represented by that series.

1 35. The apparatus of claim 33, wherein said available paths include lightpaths.

1 36. The apparatus of claim 33, wherein said available paths include one or more of  
2 optical circuits, lightpaths, and end-to-end unidirectional paths.

1 37. The apparatus of claim 33, wherein each of said paths is represented in said  
2 database by the series of two or more nodes and the interconnecting links over which  
3 that path travels.

1 38. The apparatus of claim 37, wherein each of said available paths is also  
2 represented in said database by a path channel set that includes one or more  
3 wavelengths common to all of the interconnecting links of that path.

1 39. The apparatus of claim 33, wherein access node further comprises:  
2 a regular path module to select from said paths in said database a selected path  
3 and an unallocated wavelength thereon.

- 1 40. The apparatus of claim 33, wherein access node further comprises:  
2 a disjoint path module to, based on an input path having a given one of said  
3 destinations, select from ones of said paths in said database a disjoint  
4 path and unallocated wavelength thereon.
- 1 41. The apparatus of claim 40, wherein said disjoint path module is at least to  
2 determine the intersection of the intermediate nodes of said input path and the  
3 intermediate nodes of a candidate path in said database that has the same source and  
4 destination nodes as said input path.
- 1 42. The apparatus of claim 40, said disjoint path module is at least to determine the  
2 intersection of the interconnecting links of said input path and the interconnecting links  
3 of a candidate path in said database that has the same source and destination nodes as  
4 said input path.
- 1 43. The apparatus of claim 33, wherein said access node further comprises:  
2 an allocate module to cause allocation of paths and wavelengths thereon in real  
3 time.
- 1 44. The apparatus of claim 33, wherein said access node further comprises:  
2 a link state database to store, for each link connected to said access node, a link  
3 state structure to store a port of the access node to which that link is  
4 connected and available wavelengths on that link; and  
5 a link protocol module to populate said link state database.
- 1 45. An apparatus comprising:  
2 an access node, to be coupled in a wavelength division multiplexing optical  
3 network, including,  
4 a database organized by the destination nodes of the available paths  
5 from the access node to others of said access nodes, each such  
6 destination node having associated to it those of the available  
7 paths that lead to that destination node, each such available path  
8 having associated to it a path channel set that includes one or  
9 more wavelengths common to all of the interconnecting links of  
10 that path, and

11                   a disjoint path module to select, based at least in part on an input path, a  
12                   disjoint path from the available paths associated in said database  
13                   with the same destination nodes as said input path and select an  
14                   unallocated wavelengths thereon.

1    46.    The apparatus of claim 45, wherein said disjoint path module is at least to select  
2    one or more of fully node disjoint type paths and maximally node disjoint type paths.

1    47.    The apparatus of claim 45, wherein said disjoint path module is at least to select  
2    one or more of fully link disjoint type paths and maximally link disjoint type paths.

1    48.    The apparatus of claim 45, wherein said disjoint path module is at least to  
2    determine the intersection of the intermediate nodes of said input path and the  
3    intermediate nodes of a candidate path in said database that has the same source and  
4    destination nodes as said input path.

1    49.    The apparatus of claim 45, said disjoint path module is at least to determine the  
2    intersection of the interconnecting links of said input path and the interconnecting links  
3    of a candidate path in said database that has the same source and destination nodes as  
4    said input path.

1    50.    The apparatus of claim 45, wherein said available paths include lightpaths.

1    51.    The apparatus of claim 45, wherein said available paths include one or more of  
2    optical circuits, lightpaths, and end-to-end unidirectional paths.

1    52.    The apparatus of claim 45, wherein each of said available paths in each of said  
2    databases is represented by the series of two or more nodes and the interconnecting  
3    links over which the paths travels.

1    53.    The apparatus of claim 45, wherein the path selection module further comprises:  
2           a regular path module to select a path from said available paths in said database  
3           associated with an input destination node and select an unallocated  
4           wavelengths thereon.



1 54. The apparatus of claim 45, wherein said access node also includes an allocate  
2 module, coupled to said disjoint path module, to allocate in real time lightpaths having  
3 that access node as a source node.

1 55. The apparatus of claim 45, wherein said access node including modules to  
2 participate in a distributed search based scheme to build and maintain said database.

1 56. The apparatus of claim 45, wherein said access node further comprises:  
2 a start up module to generate and transmit to adjacent nodes connectivity  
3 request messages to determine possible paths having said access node as  
4 a source node and meeting a set of zero or more connectivity constraints;  
5 and  
6 a connectivity request module, responsive to each received connectivity request  
7 messages, to determine any adjacent nodes to which the possible path  
8 that the connectivity request message has already collected can be  
9 extended to form additional possible paths having the originating access  
10 node as the source node and meeting the set of connectivity constraints,  
11 to transmit a message carrying that determination, and to propagate said  
12 connectivity request message to any adjacent nodes that may be able to  
13 determine additional possible paths having the originating access node  
14 as the source node and meeting the set of connectivity constraints.

1 57. The apparatus of claim 56, wherein each of the messages carrying a  
2 determination is transmitted back to the originating access node of the connectivity  
3 request message responsive to which that message was generated, and wherein each of  
4 said start up modules is also to build said database in its access node responsive to  
5 receiving the messages carrying determinations of additional possible paths having the  
6 access node as the source node and meeting the set of connectivity constraints.

1 58. The apparatus of claim 45, wherein said access node further comprises:  
2 a module to build and maintain said database based upon data collected by  
3 OSPF.

1 59. The apparatus of claim 45, wherein said access node further comprises:

2 for each link connected to the access node, a link channel set representing at  
3 least certain wavelengths on that link available for establishing a  
4 lightpath, wherein a lightpath is a wavelength and a path, wherein the  
5 path of a given lightpath is a series of two or more nodes and links  
6 interconnecting them through which traffic is carried by the wavelength  
7 of that lightpath, wherein said series of nodes respectively starts and  
8 ends with a source node and a destination node, wherein the available  
9 paths in said database are the lightpaths from the access node to others  
10 of said access nodes using the wavelengths in said link channel sets.

1 60. An apparatus comprising:  
2 an access node, to be coupled in a wavelength division multiplexing optical  
3 network, including,  
4 a database to store available paths with costs from that access node to  
5 reachable destination nodes in said database, wherein each of  
6 said available paths is a series of nodes and interconnecting links  
7 in said optical network over which that path travel, said database  
8 to store said available paths grouped by common destination  
9 nodes and sorted in each group at least in part by cost, each of  
10 said paths having associated with it in said database the  
11 wavelengths available on that path.

1 61. The apparatus of claim 60, wherein said database includes a destinations  
2 structure to store each of said destinations in a single entry, each of said entries being  
3 associated with the sequence of nodes and links of those of the available paths that  
4 reach that entries destination.

1 62. The apparatus of claim 60, said access node further comprising:  
2 a disjoint path module, coupled to said database, to select, based at least in part  
3 on an input path, a disjoint path from the available paths associated in  
4 said database with the same destination node as said input path and  
5 select an unallocated wavelengths thereon.

1 63. The apparatus of claim 62, wherein said disjoint path module is at least to  
2 determine the intersection of the intermediate nodes of said input path and the

3 intermediate nodes of a candidate path in said database that has the same source and  
4 destination nodes as said input path.

1 64. The apparatus of claim 62, said disjoint path module is at least to determine the  
2 intersection of the interconnecting links of said input path and the interconnecting links  
3 of a candidate path in said database that has the same source and destination nodes as  
4 said input path.

1 65. The apparatus of claim 60, said access node further comprising:  
2 a regular path module to select a the first path with an unallocated wavelength  
3 from the group of sorted paths in said database associated with an input  
4 destination node and select an unallocated wavelength thereon.

1 66. A method performed in an access node of a wave division multiplexing optical  
2 network, said method comprising:  
3 responsive to a demand for a path to a given destination node, performing the  
4 following,  
5 accessing a database storing available paths with costs from the access  
6 node to reachable destination nodes in said optical network,  
7 wherein each path is a sequence of nodes and interconnecting  
8 links starting at said access node and ending at one of said  
9 reachable destination nodes, said available paths being stored  
10 grouped by common destination nodes and sorted in each group  
11 at least in part by the cost, each of said paths having associated  
12 with it in said database the wavelengths available on that path,  
13 selecting the group of sorted paths with the given destination node;  
14 selecting a path with an unallocated wavelength from the selected group  
15 of sorted paths having the given destination node; and  
16 selecting a wavelength on the selected path.

1 67. The method of claim 66, wherein said selecting said path further comprises:  
2 selecting the first path in the sorted order with an unallocated wavelength.

1 68. The method of claim 66, wherein said selecting said path further comprises:  
2 accessing from the database the nodes and/or links of the selected path; and

3           determining that the accessed nodes and/or links are sufficiently disjoint from a  
4           set of input nodes and/or links to meet a set of disjointness constraints.

1   69.    The method of claim 68, wherein said set of disjointness constraints include one  
2   or more of maximally link disjoint, fully link disjoint, maximally node disjoint, and  
3   fully node disjoint.

1   70.    A method performed in an access node of a wave division multiplexing optical  
2   network, said method comprising:

3           locating a reachable destination node in a structure of a database, wherein said  
4           structure stores a non-duplicative set of the plurality of destination nodes  
5           in the optical network reachable with available paths from the access  
6           node, wherein said database associates to each of said plurality of  
7           destination nodes in the structure each of the sequences of nodes and  
8           interconnecting links of those of the available paths that lead to that  
9           destination node sort at least in part by cost, each such available path  
10          having associated to it the set of one or more available wavelengths  
11          along that path; and  
12          accessing from the database the nodes and/or links of a selected one of the  
13          available paths associated with the located one of said plurality of  
14          destination nodes; and  
15          selecting from the database an unallocated one of the set of available  
16          wavelengths along the selected path.

1   71.    The method of claim 70, wherein said method further includes:  
2          determining that the accessed nodes and/or links are sufficiently disjoint from a  
3          set of input nodes and/or links to meet a set of disjointness constraints.

1   72.    The method of claim 71, wherein the set of disjointness constraints includes one  
2   of fully node disjoint, maximally node disjoint, fully link disjoint, and maximally link  
3   disjoint.

1   73.    The method of claim 70, wherein said available paths are lightpaths.

1   74.    The method of claim 70, wherein said available paths are optical circuits.

1 75. The method of claim 70, wherein the database includes for each of the sets of  
2 wavelengths a status for each wavelength, wherein said status includes allocated and  
3 unallocated states.

1 76. A method comprising:  
2 transmitting to each adjacent node of an access node of a wavelength division  
3 multiplexing optical network a connectivity request message to be  
4 propagated to determine possible end to end paths having said access  
5 node as a source node and meeting a set of zero or more connectivity  
6 constraints, wherein an end to end path is a series of two or more of  
7 nodes connected by links on which a set of wavelengths is available for  
8 establishing a lightpath; and  
9 receiving responsive connectivity messages identifying collected possible end to  
10 end paths and a path channel set for each identifying the available  
11 wavelengths;  
12 storing in a database the collected end to end paths grouped by common  
13 destination nodes;  
14 storing in said database the path channel set for each of the collected end to end  
15 paths; and  
16 associating in said database each of the stored path channel sets to the  
17 corresponding stored end to end path.

1 77. The method of claim 76, wherein said storing includes in said database the  
2 collected end to end paths further comprises:  
3 associating a cost to each of said end to end paths; and  
4 sorting the end to end paths in each group at least in part by said costs.

1 78. The method of claim 77, further comprising:  
2 responsive to a demand for a path to a given destination node, performing the  
3 following,  
4 selecting the group of sorted end to end paths with the destination node;  
5 and  
6 selecting a path with an unallocated wavelength from the selected group  
7 of sorted end to end paths having the given destination node; and

8 selecting a wavelength on the selected path.

1 79. The method of claim 77, wherein said selecting said path further comprises:  
2 selecting the first path in the sorted order with an unallocated wavelength.

1 80. The method of claim 77, wherein said selecting said path further comprises:  
2 accessing from the database the nodes and/or links of the selected path; and  
3 determining that the accessed nodes and/or links are sufficiently disjoint from a  
4 set of input nodes and/or links to meet a set of disjointness constraints.

1 81. The method of claim 80, wherein said set of disjointness constraints include one  
2 or more of maximally link disjoint, fully link disjoint, maximally node disjoint, and  
3 fully node disjoint.

1 82. The method of claim 77 further comprising:  
2 responsive to a demand for a path to a given destination node, performing the  
3 following,  
4 selecting the group of sorted end to end paths with the given destination  
5 node;  
6 selecting as an initial path the first path with an unallocated wavelength  
7 from the selected group;  
8 selecting as a subsequent path the first path with an unallocated  
9 wavelength from the selected group whose nodes and/or links are  
10 sufficiently disjoint from the nodes and/or links of the initial path  
11 to meet a set of disjointness constraints; and  
12 selecting an unallocated wavelength on said initial path; and selecting an  
13 unallocated wavelength on said subsequent path.

1 83. The method of claim 82, wherein said set of disjointness constraints include one  
2 or more of maximally link disjoint, fully link disjoint, maximally node disjoint, and  
3 fully node disjoint.

1 84. A method performed in an access node of a wave division multiplexing optical  
2 network, said method comprising:  
3 selecting, from a database storing available paths with costs from the access  
4 node to reachable destinations organized by said reachable destinations,

5 a different one of a set of the available paths associated with the same  
6 destination node as a previously selected path, wherein each of said  
7 available paths is represented in said database by the series of two or  
8 more nodes and the interconnecting links over which that path travels,  
9 wherein each of said available paths in said database has associate to it a  
10 path channel set that includes one or more wavelengths common to all of  
11 the interconnecting links of that path; and  
12 determining the currently selected path is sufficiently disjoint from the  
13 previously selected path to meet a set of disjointness constraints through  
14 calculating the intersection set of the nodes and/or links of the currently  
15 selected path accessed from said database and the previously selected  
16 path; and  
17 selecting from the path channel set in said database associated with said  
18 currently selected path an unallocated wavelength.

1 85. The method of claim 84, wherein said available paths are lightpaths.

1 86. The method of claim 84, wherein said available paths are optical circuits.

1 87. The method of claim 84, wherein the database includes for each of the path  
2 channel sets a status for each wavelength, said status including allocated and  
3 unallocated states.

1 88. The method of claim 84, wherein the set of disjointness constraints includes one  
2 of fully node disjoint, maximally node disjoint, fully link disjoint, and maximally link  
3 disjoint.